Neutrinos and Double β Decays

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Neutrino Team

- Overseer: Cheng-Ju Lin
- Encoders:
  – P. Vogel and A. Piepke (reactor neutrinos and $\beta\beta$ decay)
  – K. Nakamura (solar/atm neutrinos)
  – K. Olive (astrophysical neutrinos)
  – M. Goodman (accelerator-based neutrinos)
- Review authors:
  – K. Nakamura and S.T. Petcov
  – G. Zeller (new author)
  – Encoders also cover mini-reviews

New Since RPP2012

- Neutrino mixing and properties: 70 papers and 85 new measurements
- (0)2νββ decay: 20 papers and 25 measurements
- All three neutrino mixing angles and mass differences have been measured
- Neutrino mixing physics is in the precision measurement era
- Updated and new neutrino reviews

Mixing Angle θ_{13}

- Accelerator based experiments (T2K,MINOS) reported hints of non-zero θ_{13} in 2011
- Reactor experiments (Daya Bay and RENO) observed θ_{13} with 5-sigma significance early this year

RPP2012

$\sin^2(2\theta_{13})$

At present time direct measurements of $\sin^2(2\theta_{13})$ are derived from the reactor $\overline{\nu}_e$ disappearance at distances corresponding to the Δm^2_{32} value, i.e. L $\sim$ 1km. Alternatively, limits can also be obtained from the analysis of the solar neutrino data and accelerator-based $\nu_\mu \rightarrow \nu_e$ experiments.

VALUE	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
0.098±0.013 OUR AVERAGE					
0.086±0.041±0.030		[1] ABE	12	DCHZ	Chooz reactors
0.113±0.013±0.019		[2] AHN	12	RENO	Yonggwang reactors
0.092±0.016±0.005		[3] AN	12	DAYA	Daya Bay, Ling Ao, Ling Ao-II reactors

(0)$\nu\beta\beta$ Decays

- List of new measurements is growing rapidly
- Decided to remove older and less stringent limits to keep the table manageable
- Only best limits and limit with $T_{1/2}>10^{20}$ years are kept (87 measurements in RPP2012)
- People not happy when their measurements are not listed ☹

Half-life Measurements and Limits for Double-β Decay

In most cases the transitions $(Z,A) \rightarrow (Z+2,A) + 2e^- + (0 \text{ or } 2)\,\overline{\nu}_e$ to the 0^+ ground state of the final nucleus are listed. However, we also list transitions that increase the nuclear charge ($2e^+$, e^+/EC and ECEC) and transitions to excited states of the final nuclei (0^+_i, 2^+, and 2^+_i). In the following Listings, only best or comparable limits or lifetimes for each isotope are reported and only those with $T_{1/2} > 10^{20}$ years that are relevant for particle physics. For 2ν decay, which is well established, only measured half-lives are reported.

• • • We do not use the following data for averages, fits, limits, etc. • • •

$t_{1/2}$ (10^{21} yr)	CL%	ISOTOPE		TRANSITION	METHOD	DOCUMENT ID
$2.11 \pm 0.04 \pm 0.21$	68	^{136}Xe	2ν		EXO-200	[1] ACKERMAN 11
$0.7 \pm 0.09 \pm 0.11$	68	^{130}Te	2ν		NEMO-3	[2] ARNOLD 11
> 130	90	^{130}Te	0ν		NEMO-3	[3] ARNOLD 11
> 1.3	90	^{112}Sn	0ν	$0^+ \rightarrow 0^+_3$	γ Ge det.	[4] BARABASH 11
> 0.69	90	^{112}Sn	0ν	$0^+ \rightarrow 0^+_2$	γ Ge det.	[5] BARABASH 11
> 1.3	90	^{112}Sn	0ν	$0^+ \rightarrow 0^+_1$	γ Ge det.	[6] BARABASH 11
> 1.06	90	^{112}Sn	0ν		γ Ge det.	[7] BARABASH 11
$(2.8 \pm 0.1 \pm 0.3)$E-2		^{116}Cd	2ν		NEMO-3	[8] BARABASH 11A
$(4.4^{+0.5}_{-0.4} \pm 0.4)$E-2		^{48}Ca	2ν		NEMO-3	[9,10] BARABASH 11A
$(69 \pm 9 \pm 10)$E-2		^{130}Te	2ν		NEMO-3	[10,11] BARABASH 11A
>1100	90	^{100}Mo	0ν		NEMO-3	[10,12] BARABASH 11A
>360	90	^{82}Se	0ν		NEMO-3	[10,13] BARABASH 11A
>100	90	^{130}Te	0ν		NEMO-3	[10,14] BARABASH 11A
>16	90	^{116}Cd	0ν		NEMO-3	[10,15] BARABASH 11A
>13	90	^{48}Ca	0ν		NEMO-3	[10,16] BARABASH 11A
> 0.32	90	^{64}Zn	0ν	ECEC,g.s.	$ZnWO_4$ scint.	[17] BELLI 11D
> 0.85	90	^{64}Zn	0ν	β^+EC,g.s.	$ZnWO_4$ scint.	[17] BELLI 11D
> 0.11	90	^{106}Cd	0ν	$0^+ \rightarrow 4^+$	TGV2 det.	[18] RUKHADZE 11
$(2.35 \pm 0.14 \pm 0.16)$E-2		^{96}Zr	2ν		NEMO-3	[19] ARGYRIADES 10
> 9.2	90	^{96}Zr	0ν		NEMO-3	[20] ARGYRIADES 10
> 0.22	90	^{96}Zr	0ν	$0^+ \rightarrow 0^+_1$	NEMO-3	[21] ARGYRIADES 10
$0.69^{+0.10}_{-0.08} \pm 0.07$	68	^{100}Mo	2ν	$0^+ \rightarrow 0^+_1$	Ge coinc.	[22] BELLI 10
> 18.0	90	^{150}Nd	0ν		NEMO-3	[23] ARGYRIADES 09
$(9.11^{+0.25}_{-0.22} \pm 0.63)$E-3		^{150}Nd	2ν		NEMO-3	[24] ARGYRIADES 09
> 0.43	90	^{64}Zn	0ν	β^+EC	$ZnW0_4$ scint.	[25] BELLI 09A
> 0.11	90	^{64}Zn	0ν	ECEC	$ZnW0_4$ scint.	[26] BELLI 09A
$0.55^{+0.12}_{-0.09}$		^{100}Mo	$2\nu+0\nu$	$0^+ \rightarrow 0^+_1$	Ge coincidence	[27] KIDD 09
> 3000	90	^{130}Te	0ν		TeO_2 bolometer	[28] ARNABOLDI 08
> 0.22	90	^{64}Zn	0ν		$ZnWO_4$ scint.	[29] BELLI 08

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Some Issues for RPP14

- Stopped updating Heavy (~MeV-GeV) Neutral Lepton section in RPP2006. No consistent theoretical framework to list sterile neutrino searches. May replace it with a mini-review
- Compile non-standard neutrino interaction (NSI) limits? No NSI experts in PDG at the moment
- Global fits for neutrino mixing parameters? Need HFAG equivalent for neutrino for this to happen

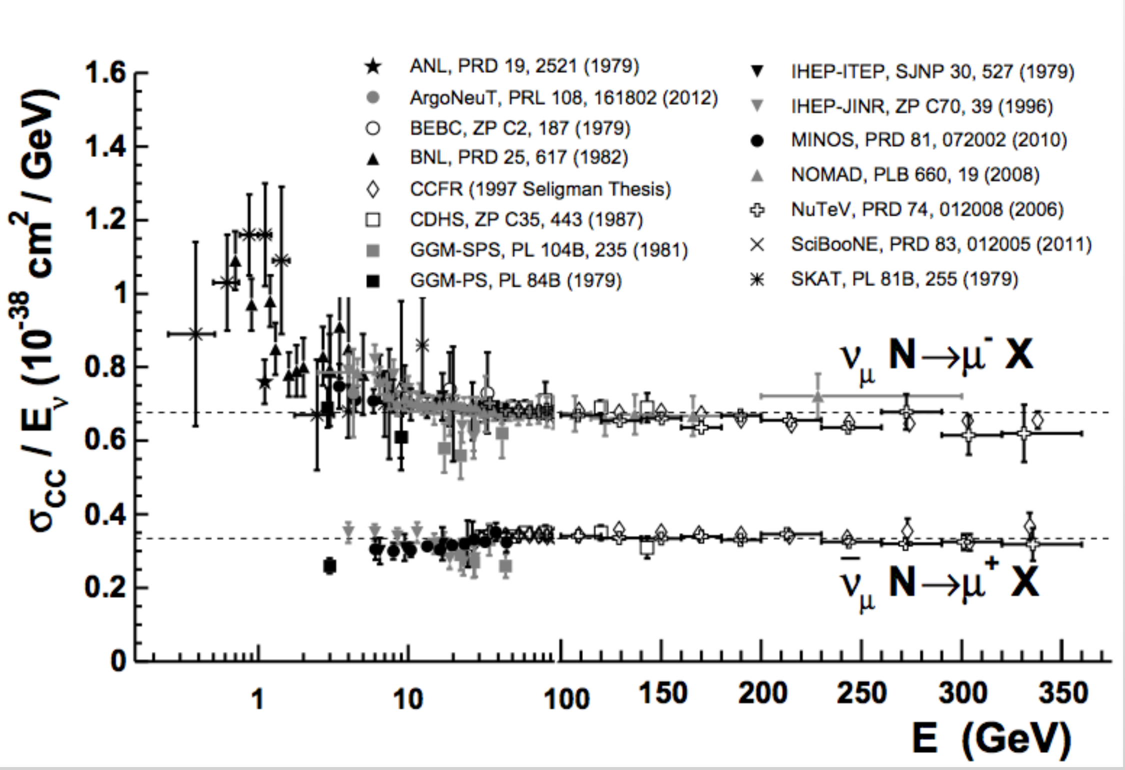
(from M. Goodman)

- Back in 2004, we adopted the neutrino mixing parameters in the 3-neutrino paradigm: Δm_{21}, Δm_{32}, $\Delta m^2_{32} \sim \Delta m^2_{31}$, θ_{12}, θ_{12}, and θ_{13}
- This works for a while. Now the experimental precision are at the level that we need to revisit this issue again
- What should we do in the mean time:
  - Do nothing and wait for mass hierarchy result
  - Adopt alternative convention (e.g. Δm^2_{atm})
  - Others?

PDG ADVISORY COMMITTEE RECOMMENDATIONS FOR NEUTRINO

Recommendation :

"Given the new emphasis in the field of low energy neutrino measurements, a review of low energy neutrino properties would be appropriate"



We have added a new review article in RPP2012 to cover low energy neutrino cross section measurements. Geralyn (Sam) Zeller is the review author.

Recommendation :

"We were pleased to learn that there will be a review article on event generators. We would like to see some discussion on neutrino event generators."

Authors of the event generators look into this and concluded that they didn't have the expertise to survey neutrino event generators. We decided to have a separate review to cover the topic. Hugh Gallagher and Yoshinari Hayato have agreed to author the neutrino generator review. The review was not ready in time for RPP2012. We will include it in the next update.

Recommendation :

"Cosmological limits on neutrino masses: we recommend that a third reader be assigned in this area, this would be helpful so that articles that discuss neutrinos in the text but not in the title or abstract can be included in the PDG Review."

We agree with the committee that if we rely solely on the default literature searches, some of the cosmological limits on neutrino masses would be missed. Our encoder, Keith Olive, if effectively the third reader. He independently adds a fair fraction of the papers to the listing that are not picked up in the scans. We doubt we miss much (if any) at the end.

Recommendation :

"We would suggest that a table of neutrino beamline parameters be included in RPP"

We have compiled the table for RPP2012 based on inputs from the official contacts of the various accelerators. S. E. Kopp was also consulted with regard to the content of the table

ν Beamlines

	PS (CERN)				SPS (CERN)				PS (KEK)	Main Ring (JPARC)
Date	1963	1969	1972	1983	1977	1977	1995	2006	1999	2009
Proton Kinetic Energy (GeV)	20.6	20.6	26	19	350	350	450	400	12	30 (50)
Protons per Pulse (10^{12})	0.7	0.6	5	5	10	10	18	50	6	135 (330)
Cycle Time (s)	3	2.3	-	-	-	-	14.4	6	2.2	2.56 (3.5)
Beam Power (kW)	0.8	0.9	-	-	-	-	55	510	5	250 (750)
Secondary Focussing	1-horn WBB	3-horn WBB	2-horn WBB	bare target	dichromatic NBB	2-horn WBB	2-horn WBB	2-horn WBB	2-horn WBB	3-horn off-axis
Decay Pipe Length (m)	60	60	60	45	290	290	290	994	200	96
$\langle E_\nu \rangle$ (GeV)	1.5	1.5	1.5	1	50,150†	20	24.3	17	1.3	0.6
Experiments	HLBC, Spark Ch.	HLBC, Spark Ch.	GGM, Aachen-Padova	CDHS, CHARM	CDHS, CHARM, BEBC	GGM,CDHS, CHARM, BEBC	NOMAD, CHORUS	OPERA, INCARUS	K2K	T2K

RPP 2012, Sec 29 pg 322 (printed edition)

	Main Ring (Fermilab)							Booster (Fermilab)	Main Injector (Fermilab)	
Date	1975	1975	1974	1979	1976	1991	1998	2002	2005	2013
Proton Kinetic Energy (GeV)	300,400	300,400	300	400	350	800	800	8	120	120
Protons per Pulse (10^{12})	10	10	10	10	13	10	12	4.5	37	(49)
Cycle Time (s)	-	-	-	-	-	60	60	0.5	2	(1.333)
Beam Power (kW)	-	-	-	-	-	20	25	12	350	(700)
Secondary Focussing	bare target	quad trip., SSBT	dichromatic NBB	2-horn WBB	1-horn WBB	quad trip.	SSQT WBB	1-horn WBB	2-horn WBB	2-horn off-axis
Decay Pipe Length (m)	350	350	400	400	400	400	400	50	675	675
$\langle E_\nu \rangle$ (GeV)	40	50,180†	50,180†	25	100	90,260	70,180	1	3-20‡	2
Experiments	HPWF	CITF, HPWF	CITF, HPWF, 15' BC	15' BC	HPWF 15' BC	15' BC, CCFRR	NuTeV	MiniBooNE, SciBooNE	MINOS, MINERνA	NOνA, MINERνA, MINOS+

C.-J. Lin – October 2012

Neutrino Landscape

Neutrino Physics is a "hot" area of research. We are expecting new results to roll off the assembly line

Physics Now:

MINOS, T2K, MiniBoone, SciBoone, MinerVa, KamLand, OPERA, Borexino, SNO, Daya Bay, Double Chooz, Reno

Near Term:

NoVa, MicroBoone

Long Term:

Hyper-K, LBNE, INO, LBNO, etc.

Similar outlook for $0\nu\beta\beta$ experiments. Expect steady flow of results for current and upcoming experiments